In Situ and Satellite Sea Surface Temperature (SST) Analyses

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1. PROJECT SUMMARY

The purpose of this project is to focus on improvements to the climate-scale sea surface temperature (SST) analyses produced at NOAA. The major effort has been the development of a new daily optimum interpolation analysis, which was designed use multiple satellite data sets as well as in situ data. At present there are two products. One product uses infrared satellite data from the Advanced Very High Resolution Radiometer (AVHRR). The second product uses AVHRR and microwave satellite data from the Advanced Microwave Scanning Radiometer (AMSR) on the NASA Earth Observing System. The AVHRR-only product began in January 1985 and the AMSR+AVHRR product began in June 2002 when the microwave satellite data became available. Both products include a large-scale adjustment of satellite biases with respect to the in situ (ship and buoy) data. Two products are needed because there is an increase in signal variance when microwave satellite data became available due to its near all-weather coverage.

Additional efforts have been carried out to improve the Extended Reconstruction SST analysis. This analysis presently uses in situ data and begins in 1854. The reconstructions were produced from a low frequency (or decadal-scale component) and from a residual high-frequency component. The high frequency analysis was performed by fitting the observed high frequency anomalies to a set of large-scale spatial-covariance modes. A new version is produced which improves the damping in the late 19th century. In addition, beginning in 1985, coverage is improved by the use of bias-adjusted satellite data.

One of the important goals of the Sustained Ocean Observing System for Climate is to improve the SST accuracy over the global ocean. Because of the high coverage of satellite data, in situ data used in the analysis tends to be overwhelmed by satellite data. Thus, the most important role of the in situ data in the analysis is to correct large-scale satellite biases. Simulations with different buoy densities showed the need for at least two buoys on a 10^o spatial grid. This will ensure that satellite biases do not exceed 0.5^oC. Using this criterion, regions were identified where additional buoys are needed, and a metric was designed to measure the adequacy of the present observing system. Improved bias correction methods now being developed may reduce the needed sampling.

Richard W. Reynolds serves on the Ocean Observation Panel of Climate (OOPC) and the Global Ocean Data and the Assimilation Experiment High Resolution Surface Temperature Pilot Project (GHRSST-PP) Science Team. Members of both groups consist of well-known national and international scientists. All work presented here follows the Ten Climate Monitoring Principles.

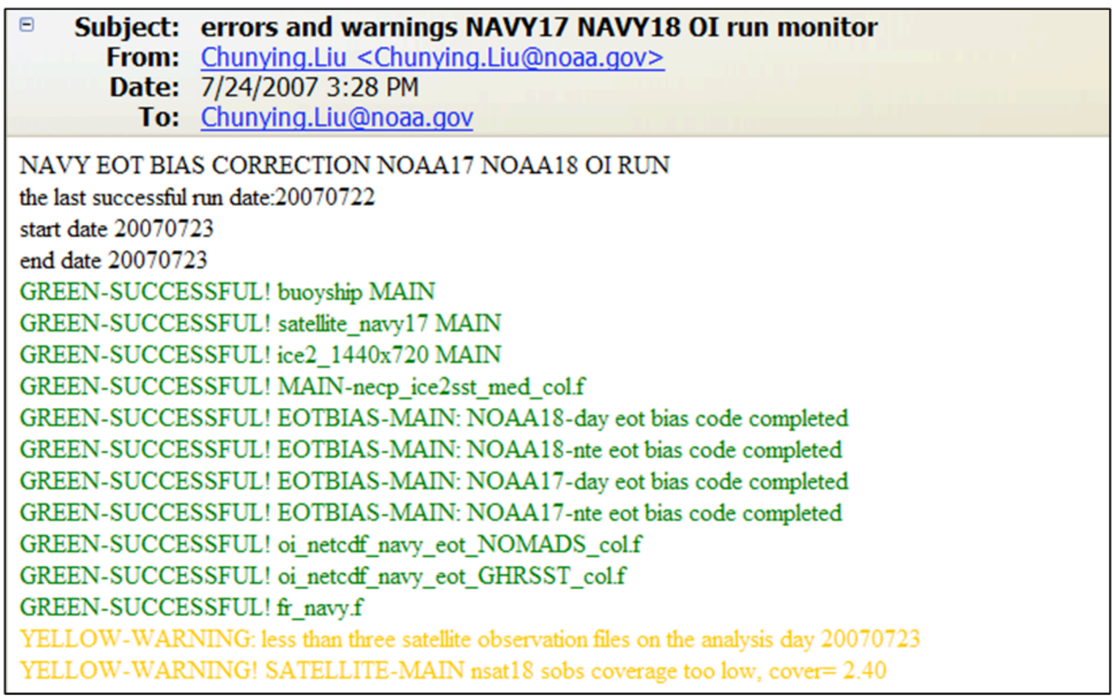
2. FY 2007 PROGRESS

2.1 The High-Resolution Daily SST Analyses

During FY2006, two new daily 1/4° SST analyses were developed: the AVHRR-only daily optimum interpolation (OI) from January 1985 to present and the AMSR+AVHRR daily OI from June 2002 to present. During FY2007 a Journal of Climate paper was written to describe the product (see Reynolds et al., 2007). Both analyses use in situ data and use a satellite bias correction. In FY2007 a web server was developed: http://www.ncdc.noaa.gov/oa/climate/research/sst/oi-daily.php. This server allows users to get information on how the analyses were generated and to download the analyses. The data are available in NetCDF and IEEE binary. The user interface also allows users to generate plots as needed and to generate digital output files in different formats including ASCII.

2.1.1 Operations

To monitor operations a system was developed to report on the success of each step. This results in a short email to the operator that summarizes each analysis step. At each step there are three possibilities indicated by a color, a successful completion (green), a warning (yellow) or a fatal error (red). Processing continues with a warning but ends with a fatal error. The color email allows the operator to tell at a glance the status of the operation. Problems can then be assessed and corrected. Examples of emails are shown in Figures 1 and 2.



Subject: errors and warnings NAVY17 NAVY18 OI run monitor
From: Chunying.Liu <Chunying.Liu@noaa.gov>
Date: 7/24/2007 3:28 PM
To: Chunying.Liu@noaa.gov

NAVY EOT BIAS CORRECTION NOAA17 NOAA18 OI RUN
the last successful run date:20070722
start date 20070723
end date 20070723
GREEN-SUCCESSFUL! buoyship MAIN
GREEN-SUCCESSFUL! satellite_navy17 MAIN
GREEN-SUCCESSFUL! ice2_1440x720 MAIN
GREEN-SUCCESSFUL! MAIN-necp_ice2sst_med_col.f
GREEN-SUCCESSFUL! EOTBIAS-MAIN: NOAA18-day eot bias code completed
GREEN-SUCCESSFUL! EOTBIAS-MAIN: NOAA18-nte eot bias code completed
GREEN-SUCCESSFUL! EOTBIAS-MAIN: NOAA17-day eot bias code completed
GREEN-SUCCESSFUL! EOTBIAS-MAIN: NOAA17-nte eot bias code completed
GREEN-SUCCESSFUL! oi_netcdf_navy_eot_NOMADS_col.f
GREEN-SUCCESSFUL! oi_netcdf_navy_eot_GHRSST_col.f
GREEN-SUCCESSFUL! fr_navy.f
YELLOW-WARNING: less than three satellite observation files on the analysis day 20070723
YELLOW-WARNING! SATELLITE-MAIN nsat18 sobs coverage too low, cover= 2.40

Figure 1. Example of an operational email summary of the analysis procedure with successful steps and warning steps. Successful steps are indicated by the color green, warnings by yellow and fatal errors by red.

Subject: errors and warnings AMSR OI run monitor
From: Chunying.Liu <Chunying.Liu@noaa.gov>
Date: 7/12/2007 9:15 AM
To: Chunying.Liu@noaa.gov

AMSR EOT BIAS CORRECTION OI RUN
the last successful run date:20070710
start date 20070711
end date 20070711
RED-STOP! SATELLITE-AMSR MAIN d-amsr-e sobs coverage too low, cover= 0.00000000E+00

Figure 2. Example of an operational email summary of the analysis procedure with an immediate fatal error. Otherwise as in Figure 1.

2.1.2 Version 2

Once version 1 was completed, several problems were noted. These problems were corrected in version 2 which has now been completed but is not yet operational.

The major problem with version 1 was that there was day-to-day noise. This was particularly evident in the Gulf Stream region (Figure 13, Reynolds et al., 2007) and was due to limited sampling. To reduce the noise the analysis was modified to use 3-days of data instead of 1. To determine if this procedure made was done correctly. Spectra were computed at the location of 43 moored buoys which had daily SST observations for at least 99% of the time for a three year period (2003-05). Buoy spectra and analysis spectra using 1 day and 3 days of data were computed. The average spectra are shown in Figure 3. The figure shows that the highest frequency values in the daily OI using 1-day of data are larger than in the buoy data. These values are reduced in the daily OI using 3-days of data to values closer to the buoy values. Version 2 uses 3 days of data in the daily OI.

Ship data is noisy and biased with respect to buoy data. However, correcting for these biases is difficult because the buoy coverage is sparse until roughly 1990 and because both sets of data are relatively sparse compared to satellite data. Initial attempts to develop even global annual time series failed to produce any clear time dependence. However, scatter plots showed that there was a consistent long term bias. An example of this is shown in Figure 3 for two separate 9 year periods. The linear fits to the data, show that ship SSTs should be reduced by roughly 0.14°C to reduce the overall ship bias with respect to buoys. This ship bias correction has been done in version 2.

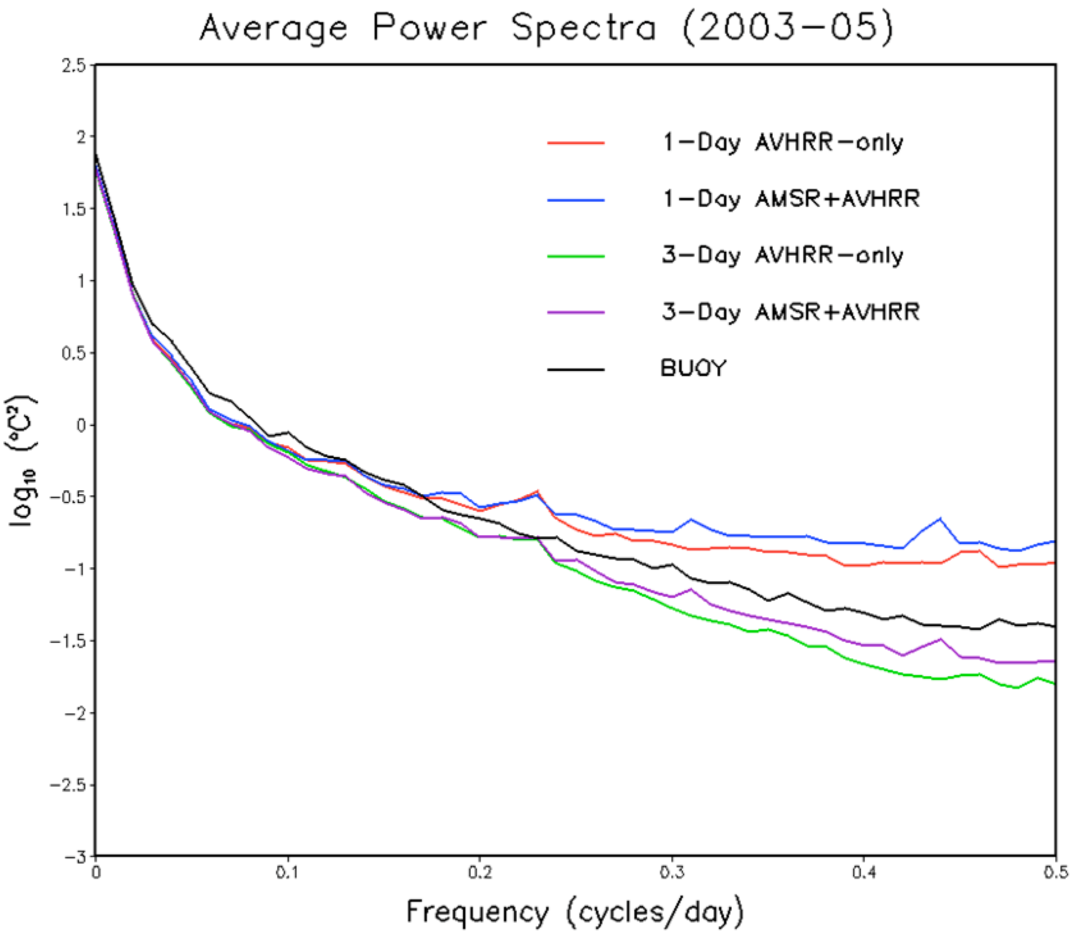


Figure 3. Average of spectra from daily buoy data and from the OI analyses for 2003-05. The spectra are computed at 43 moored buoy locations which had a daily SST value 99% of the time. At the same locations spectra are computed using the daily OI analyses using 1 and 3 days of data. Two daily OI products are considered: AVHRR-only and AMSR+AVHRR.

There are several other corrections that were made to Version 2. This includes smoothing using five 7-day satellite bias correction fields. This smoothing is needed to reduce a strong 7-day period in the bias correction. In addition, a zonal satellite bias correction is made at high latitudes where in situ data are sparse. There have also been improvements in the AMSR data to reduce the errors in SST retrievals near rain events. These improved AMSR data are used in Version 2. Finally some minor corrections were made in the land-sea tables in Version 2 to eliminate a few small errors. Most of these corrections mask out some lakes and narrow fjord channels which cannot be properly analyzed on a 1/4° grid analysis

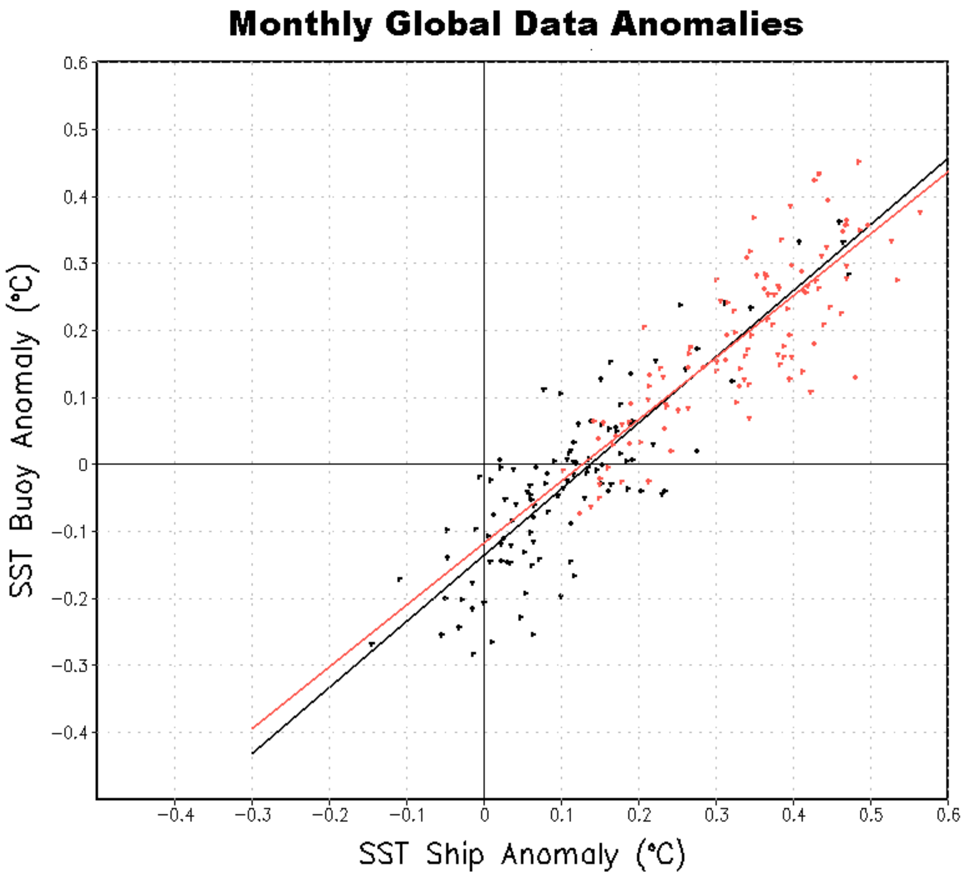


Figure 4. Monthly global data anomalies for ships and buoys. Data for 1989-1997 is in black; data for 1998-2006 is in red. A least squares fit for the two periods is also shown.

2.2 The Historic ERSST Analysis and Merged SST and Land analysis

The monthly ERSST analysis initially used a low frequency analysis on a 15-year period to begin the analysis. The reconstructions were designed to analyze signals supported by the historical sampling, with damping of anomalies when sampling was insufficient to analyze the climate-scale signal. Deciding how much sampling was sufficient was based on the data themselves and on estimates of spatial and temporal scales of the low frequency components. In the Smith and Reynolds (2004) these decisions were conservative, to ensure that data noise would not contaminate the analysis in sparse-sampling periods. A disadvantage of such conservative decisions is that they may lead to overly damped analyzed anomalies early in the historical record.

Beginning in FY06, simulated SST anomaly data from the Geophysical Fluid Dynamics Laboratory (GFDL) Climate Model 2.1 (CM2.1) were used to tune both low frequency and high frequency parameters. During FY07 the tuning procedure was completed. In addition, beginning in 1985 bias-adjusted SST satellite data were added to the in situ data. New fields using the improved tuning and satellite data were generated (version 3). The full procedure is described in Smith et al. (2007) and was also applied to in situ land surface temperatures. The merged SST and land surface temperatures are shown as global annual averages in figure 5 for the new version (version 3) and the older version (version 2). In addition, a merged analysis produced jointly by the U.K. Met Office Hadley Centre and the University of East Anglia's Climatic Research Unit (HadCRUT3v, Brohan et al. 2006) is also shown. Comparisons show that all anomalies have similar global variations throughout the analysis period. Differences are less than the 95% confidence limits of the merged version 3 analysis. Note that the confidence limits are wide early in the 20th century due to insufficient sampling and bias uncertainty. They decrease greatly between 1930 and 1950 due to increased sampling, and they increase slightly after 1950 due to increasing urbanization bias uncertainty.

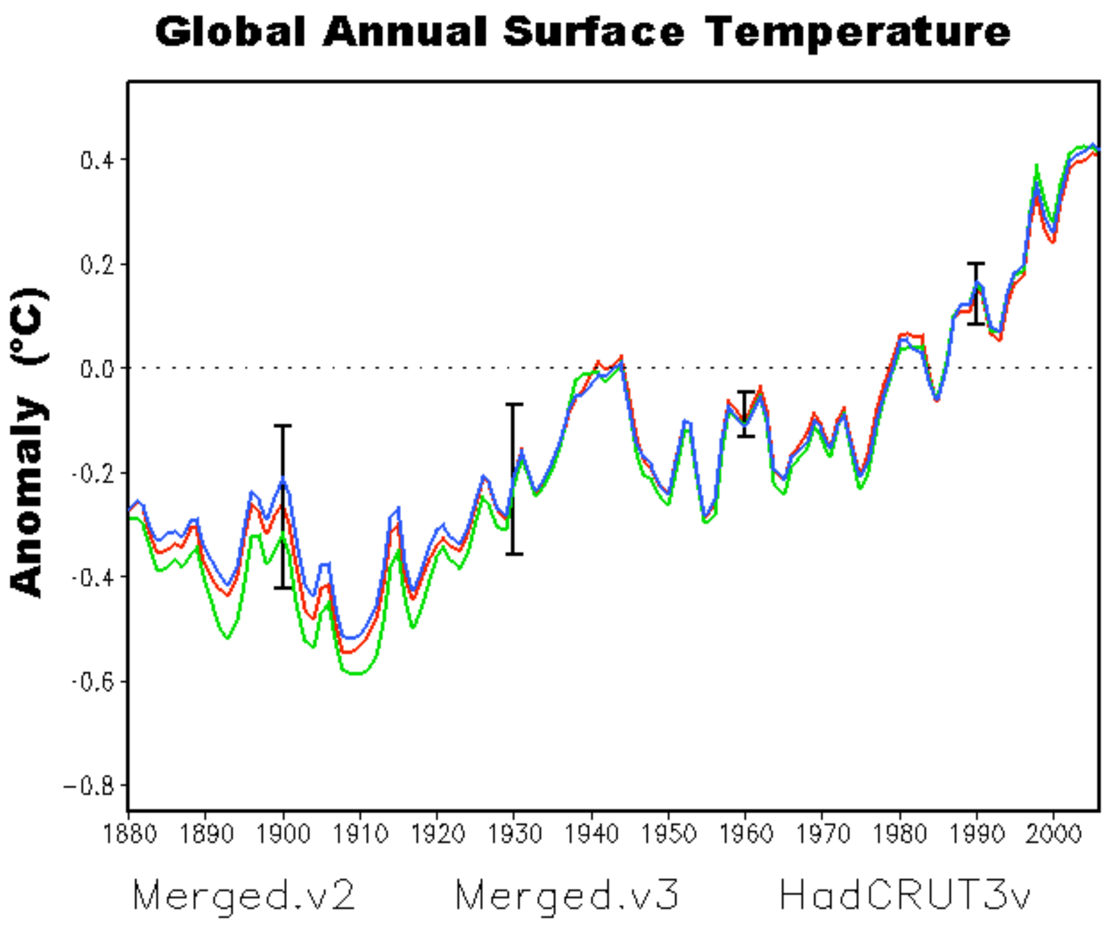


Figure 5. Global and annual merged temperature anomalies from Version 2 (Merged.v2), the improved analysis Version 3 (Merged.v3), and from UK HadCRUT3v. The base periods are adjusted to match the 1971-2000 base used in the improved analysis. A 1-2-1 smoother has been applied to each time series of annual averages. The 95% confidence limits reflecting all errors estimated for Merged.v3 are drawn for the years 1900, 1930, 1960, and 1990.

The SST analyses (ERSST.v2 and ERSST.v3) are available to uses in ASCII and NetCDF. They can be accessed from the web page: http://www.ncdc.noaa.gov/oa/climate/research/sst/sst.html

2.3 Design of an In Situ SST Network to Improve the SST Analysis

During the preceding years, an in situ network to correct "potential satellite bias errors" was determined using simulated biased satellite retrievals and simulated unbiased buoy data. The maximum "potential satellite bias error" was selected to be 2^{o}C as a worse case. Thus, the "potential satellite bias error" would be 2^{o}C if there were no in situ data to correct the bias. The data density of the present in situ network was evaluated to determine where more buoys are needed. These buoys could be either moored or drifting. However, because of the high cost of moored buoys they will be assumed to be drifters. To reduce the potential satellite bias to below 0.5^{o}C, a buoy density of about 2 buoys/10^{o} grid is required. The present in situ SST observing system was evaluated to define an equivalent buoy density allowing ships to be used along with buoys according to their random errors. These figures are operationally produced seasonally and are used to guide surface drifting buoy deployments. For more details see Zhang et al (2006).

References

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